

REPROCESSING OLD MINE TAILINGS TO RECOVER COPPER AND PRECIOUS METALS USING FROTH FLOTATION

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ABSTRACT - The old tailings from mine dumps in Namibia contain not only copper but also precious metals and other metal values, such as lead and zinc, which should be recovered to supplement the production of metals from ores. X-ray fluorescence (XRF) analysis of the tailings showed that it contained 0.8% Cu, 40 ppm Au, 60 ppm Ag, 0.9% Pb, 0.7% Zn and 1% Fe. Batch roughing tests were conducted to investigate the effect of pH, collector (PAX) dosage, and sulphidiser (Na₂S) dosage on the recovery of copper and precious metals (Ag and Au). Results for flotation test work showed that recovery of metal values depends on the three operating variables. Maximum recoveries of Cu (52%), Ag (53%) and Au (44%) were achieved at pH 10.5, PAX dosage of 47 g/t, Na₂S dosage of 109 g/t and 12-minute residence time. Testwork is still in progress to improve the recoveries of copper, gold and silver.

Keywords: Circular Economy, Flotation, Mine Tailings, Copper.

INTRODUCTION

The ore deposits around the world are depleting, with new discoveries becoming fewer. In the era of green energy transition and fourth industrialisation, it is expected that the demand for copper and other critical metals will keep increasing. Mine wastes, such as tailings, are now potential resources (secondary sources) of metal values. Millions of tonnes of tailings have been accumulated around the world after decades of mining operations. Re-processing the tailings not only allows the recovery of metal values to ensure an adequate supply of metals but also mitigates environmental impacts.

Different methods for the recovery of copper and other metals from copper tailings have been investigated. This includes flotation [1-3], leaching [3-5] and sulphation roasting-leaching [6]. Froth flotation is widely used for the beneficiation of sulfide minerals by exploiting the differences in the surface properties of minerals. The old tailings, which may have altered sulphide minerals, could require sulphidisation during flotation. The particle size of the flotation feed plays a critical role in the efficiency of the

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flotation process. Fine particles are unable to collide with air bubbles, and the coarse particles are unable to attach to the bubbles. Tailings contain mainly fine particles, which could pose process challenges when applying flotation as a beneficiation method. The various methods, discussed in detail elsewhere [7], which can be employed to improve the flotation of fine tailings, include microbubble flotation, column flotation, nanobubble flotation, polymer flocculation, shear flocculation, oil agglomeration and carrier flotation.

Mining activities around Tsumeb began in the early 1900s. A significant amount of tailings was accumulated from the operations for different eras (classified based on the technologies that were used in the processing plants). This study used the old tailings from the pre-1960 era to carry out mineralogical characterisation and evaluate the flotation characteristics of the mineral phases in the tailings. The study aimed to investigate the effect of pH, collector concentration and sulphidiser concentration on the recovery of copper and precious metals (gold and silver) contained in the tailings.

MATERIALS AND METHODS

Sample preparation and characterisation

The old tailings were collected from the mine dumps around Tsumeb in Namibia. The composite sample used for the test work was composed of samples from various locations and depths within the mine dumps. Mineralogical characterisation using binocular microscopy of the tailings sample was done to identify the mineral phases present in the ore. The benchtop Thermo Scientific X-Ray Fluorescence (XRF) machine was used to determine the chemical composition of the sample.

Flotation procedures

The 'as received' sample was dry milled to have a P_{80} of 38 μm . The mill product was then split into 500 g subsamples, which were used for batch flotation tests. The bottle-driven Magotteaux flotation machine, fitted with a 2.5 L cell, was used to conduct the flotation experiments. Figure 1 shows the scope of the flotation testwork programme. In Phase 1, the residence time was fixed at 5 minutes while the operating parameters were varied at different levels, i.e., pH (natural pH (~ 8.1), 9.5, 10.0 and 10.5), collector (potassium amyl xanthate (PAX)) concentration (47, 109 and 172 g/t) and sulphidiser (Na_2S) concentration (0, 47, 109 and 172 g/t). Pine oil was used as a frothing agent, and its concentration was fixed at 200 g/t in all tests in Phase 1. Sodium hydroxide (NaOH) was used for pH adjustment. The best combination (yielding the highest recoveries of Cu, Ag, and Au) of pH, PAX concentration, and Na_2S concentration was used in Phase 2, where the total residence time was increased to 12 minutes, and four kinetic concentrate samples (each for 3 minutes) were collected.

The scalping of the concentrate was done every 15 seconds in all tests. The impeller speed and airflow rate were kept constant at 800 rpm and 6.5 L/min respectively. Tap water was used to prepare the slurry for flotation, and deionised water was used to make up the solution of reagents. In all flotation tests, the concentrates and tailings were filtered, dried, weighed and then assayed using the benchtop XRF machine.

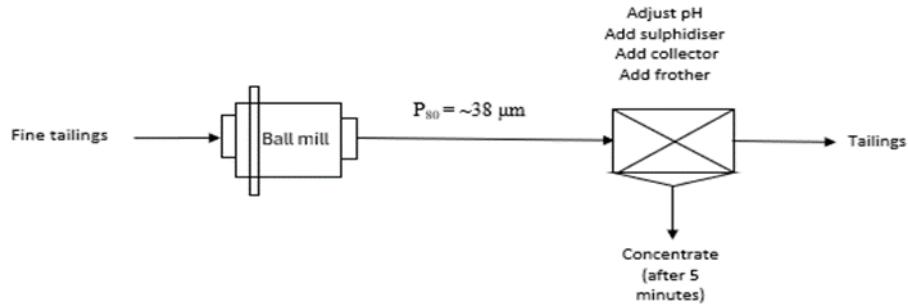


Figure 1 Scope of work for Phase 1

RESULTS AND DISCUSSION

Chemical and mineralogical composition of the old tailings

Table 1 shows the XRF assays for the two head samples. It can be observed that the tailings had precious metals (Ag and Au) in addition to the base metals (Cu, Pb and Zn) and iron. The average grade of copper was 0.75%. Mineralogical examination was performed using the binocular microscope. Various phases were identified under the microscope. In Figure 2a, the main minerals are quartz, mainly stained to brown colour, and constitute almost 90% of the field of view; calcite and dolomite (mainly white), almost 8% of the field of view. The black to bluish coloured phases are the sulphide bornite (makes up about 1.0 % in the specimen). Some grains with a brown-black colour are taken to be iron oxides, and chalcopyrite being altered to oxides. In Figure 2b, the main minerals are quartz, mainly stained to brown colour, and constitute almost 75% of the field of view; calcite and dolomite (mainly white), almost 20% of the field of view; with some dolomites being grey in colour (bottom right of photograph in Figure 2c). The black to bluish coloured phases are the sulphide bornite (makes up about 0.5-1.5% in the specimen). In Figure 2c, the main minerals are quartz, colourless to brown; calcite and dolomite (mainly white), with some dolomites being grey in colour (bottom right of photograph in Figure 2c). The black to bluish coloured phases are the sulphide bornite. Cerussite and anglesite are also present in the tailings and perhaps could be products of re-precipitation and not original grains. Scanning electron microscopy (SEM) analysis would be required to resolve whether they are original grains or a late precipitation after tailings were deposited. Cerussite occurs as small, needle-like phases, whereas anglesite is white and crystalline. Smithsonite, the Zn-bearing carbonate is also present in the tailings.

Table 1 XRF assays for the head samples

Head sample	g/t		(%)							
	Ag	Au	Cu	Fe	S	Pb	Zn	Ca	Si	Others
1	39.6	59.3	0.75	1.18	0.098	0.88	0.66	20.56	20.6	~56.19
2	44.7	61.0	0.75	1.16	0.108	0.89	0.66	20.18	19.9	~56.33

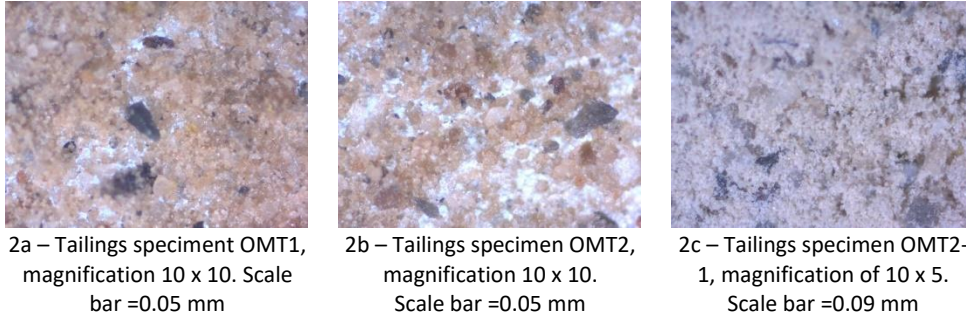


Figure 2 Scope of work for differential flotation of Pb and Cu concentrates

Milling and Flotation results

The 80% passing size of the ‘as received’ sample was about 106 μm , while that of the flotation feed (mill product) was about 38 μm . Figures 3 and 4 show the effects of collector dosage, pH and sulphidiser on the recovery of copper from the tailings. From Figure 3, it can be observed that for different pH levels, the relationships between copper recovery and collector dosages are different. For pH 9.5, recovery increases with the collector dosage. On the other hand, for pH 10.5, recovery decreases with the collector dosage. For the intermediate pH of 10, recovery initially increases with collector dosage up to 109 g/t, beyond which it decreases with the collector dosage. Optimisation of recovery has to be determined by finding the optimal combination of these two variables and other variables (e.g., concentrations of sulphidiser and frother). As shown in Figure 4, the relationship between copper recovery and sulphidiser concentration is dependent on the pulp’s pH and PAX concentration. For both natural pH and pH 10, the copper recovery increased with sulphidiser concentration when the PAX concentration was 47 g/t. For the PAX concentrations of 109 and 172 g/t, copper recovery increases with the sulphidiser concentration. The mass pull increased with the recovery, with the maximum mass pull being 16% (w/w). The maximum concentrate grade was about 2.8% Cu (corresponding to the recovery of approximately 35% Cu). The maximum recovery was about 38% Cu. Recoveries of Ag and Au were plotted against the recovery of copper in Figure 5. Recoveries for both Ag and Au increase with the recovery of Cu. This implies that Au and Ag are closely associated with the mineral phases of copper.

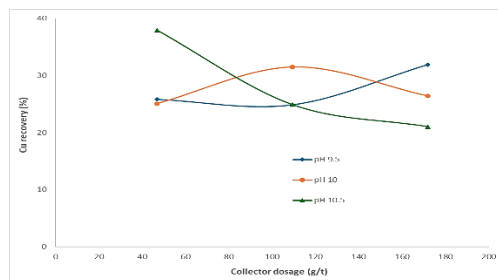


Figure 3 Effect of collector dosage and pH on copper recovery (Na₂S dosage was fixed at 100 g/t)

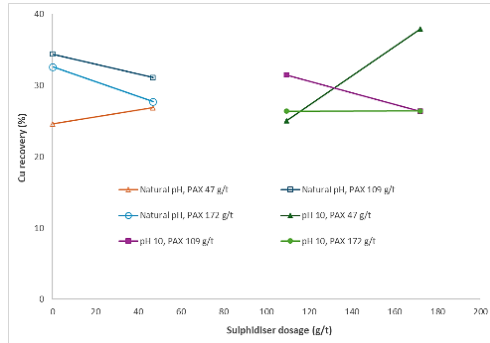


Figure 4 The effect of Na₂S on copper recovery at different pH levels and PAX dosages

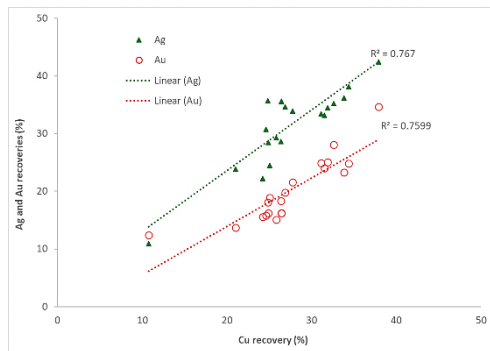


Figure 5 Relationship between recoveries of Cu, Ag, and Au

The results for a limited scope of Phase 2 conducted so far are shown in Table 2. The test conditions are shown in Figure 1. For the two tests conducted under the same conditions, the recovery was increased from 38% Cu (see Figure 5) to 51% Cu. It should be noted that no sulphidiser was added in stages two to four for the reported results in Table 2. There is scope to increase the recovery by adding a sulphidiser in stages two to four. Alternative collectors are also being considered in the ongoing testwork. Furthermore, the effect of the frother type and concentration is yet to be investigated. Considering the low content of valuable metals and altered mineral sulphide phases of copper, the authors acknowledge that hydrometallurgical treatment of the material may be the best option, as also recommended by other researchers [8]. Hydrometallurgical processing of the material to recover copper and other metals will be investigated in a future study.

Table 2 Summary of results for Phase 2

Test #	Mass pull (%)	Recoveries (%)			Concentrate grade			Tailings grade (ppm)		
		Cu	Ag	Au	Cu (%)	Ag (ppm)	Au (ppm)	Cu	Ag	Au
Run 1	28.70	52	47	43	1.41	188	298	5500	29.5	50.5
Run 2	26.19	52	59	44	1.66	191	296	5470	21.6	45.8

CONCLUSION

A series of batch flotation experiments were conducted on the old tailings enriched with metal values, 0.8% Cu, 40 ppm Au, 60 ppm Ag, 0.9% Pb, 0.7% Zn and 1% Fe. Batch roughing tests were conducted to investigate the effect of pH, collector (PAX) dosage, and sulphidiser (Na_2S) dosage on the recovery of copper and precious metals (Ag and Au). For the scope of work currently reported in this paper, maximum recoveries of Cu (38%), Ag (42%) and Au (35%) were achieved at pH 10.5, PAX dosage of 47 g/t and Na_2S dosage of 109 g/t. The recoveries were further increased to averages of 52%, 53% and 44% for Cu, Ag and Au, respectively, when the residence time was increased from 5 minutes to 12 minutes. The concentrate grade decreased to an average of 1.5% Cu, and mass pull increased from 16% (w/w) to about 27% (w/w). Testwork is still in progress to improve the recoveries of copper, gold and silver.

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REFERENCES

1. N. Terbish, A. Ganzorig, D. Davaajargal, and B. Baatar, *Reprocessing of tailing from Erdenet copper ores: Optimisation of the flotation*, no. Resat. Atlantis Press International BV, 2023. doi: 10.2991/978-94-6463-318-4_4.
2. M. Santander and L. Valderrama, "Recovery of pyrite from copper tailings by flotation," *J. Mater. Res. Technol.*, vol. 8, no. 5, pp. 4312–4317, 2019, doi: 10.1016/j.jmrt.2019.07.041.
3. R. S. Magwaneng, A. Batnasan, K. Haga, and A. Shibayama, "Development of a Combined Flotation and High Pressure Leaching Process for Copper and Nickel Recovery from Mine Tailing," *J. Miner. Mater. Charact. Eng.*, vol. 05, no. 03, pp. 118–131, 2017, doi: 10.4236/jmmce.2017.53010.
4. Y. Wang, S. Wen, Q. Feng, Y. Xian, and D. Liu, "Leaching characteristics and mechanism of copper flotation tailings in sulfuric acid solution," *Russ. J. Non-Ferrous Met.*, vol. 56, no. 2, pp. 127–133, 2015, doi: 10.3103/S1067821215020170.
5. L. Avramović, R. Jonović, M. Bugarin, R. Marković, J. Stevanović, and M. Jonović, "Leaching of Flotation Tailings," *18th Int. Res. Conf. Trends Dev. Mach. Assoc. Technol. TMT 2014 Budapest, Hungary, 10-12 Sept. 2014*, no. November 2021, pp. 481–484, 2014, [Online]. Available: <https://www.tmt.unze.ba/proceedings2014.php>
6. M. Ozer, "Cobalt and copper recovery from the ancient flotation tailings by selective sulfation roast-leaching process," *J. Min. Metall. Sect. B Metall.*, vol. 55, no. 3, pp. 315–324, 2019, doi: 10.2298/JMMB190304043O.
7. M. Bilal *et al.*, "The Challenges and Prospects of Recovering Fine Copper Sulfides from Tailings Using Different Flotation Techniques: A Review," *Minerals*, vol. 12, no. 5, 2022, doi: 10.3390/min12050586.
8. V. Trifunović, L. Avramović, D. Božić, M. Jonović, D. Šabaz, and D. Bugarin, "Flotation Tailings from Cu-Au Mining (Bor, Serbia) as a Potential Secondary Raw Material for Valuable Metals Recovery," *Minerals*, vol. 14, no. 9, p. 905, 2024, doi: 10.3390/min14090905.